Evolving Adjustments to External (Gamma) Slope Factors for CERCLA Radiation Risk Assessments – the MCNP Years

Stuart Walker
U.S. Environmental Protection Agency
Office of Superfund Remediation
and Technology Innovation (OSRTI)
Science Policy Branch

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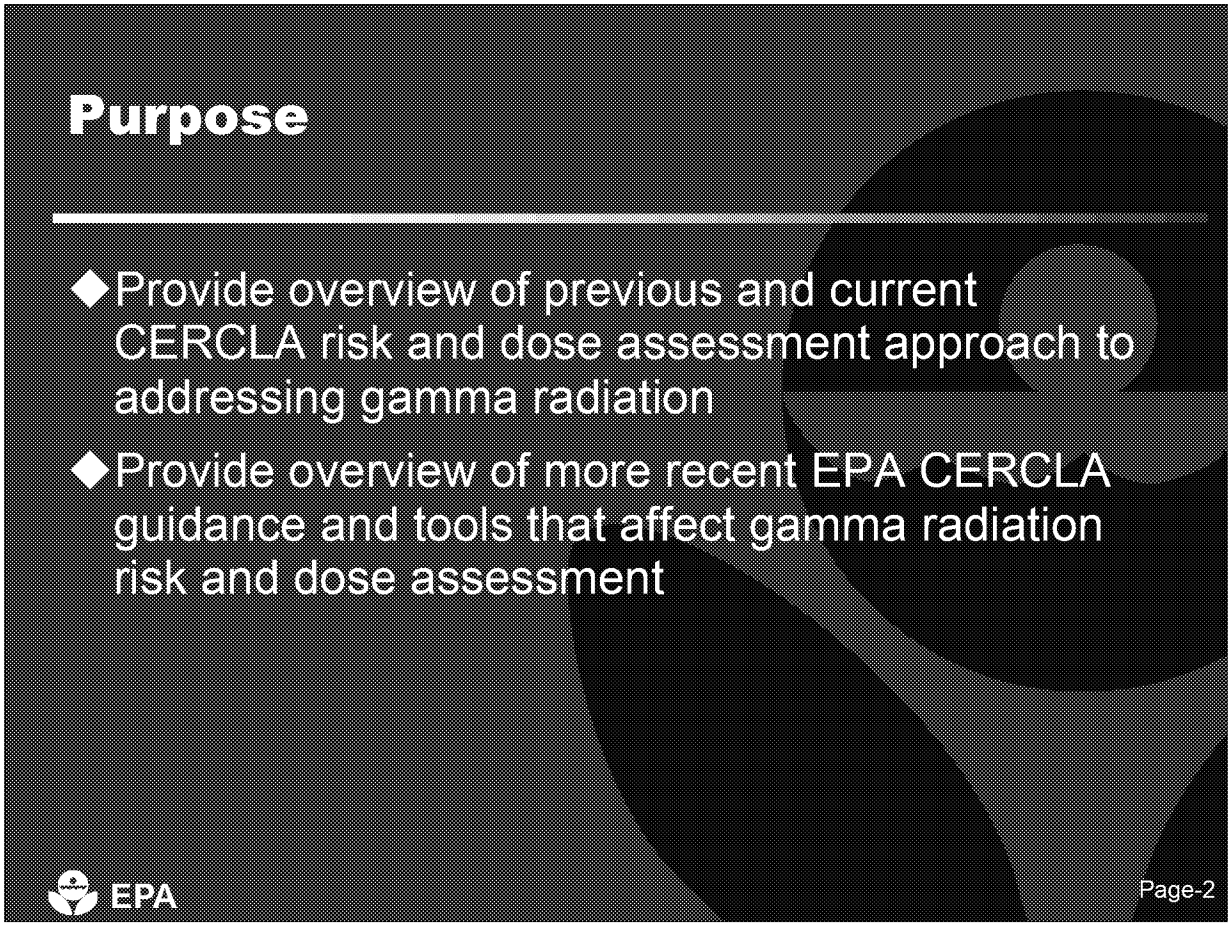

The focus of this presentation is on how radiation is addressed by the Superfund program, consistent with CERCLA and the NCP. The presentation will also provide a brief overview of guidance documents that were developed to address policy issues (such as interpretation of particular ARARs) and electronic tools for addressing radioactively contaminated sites.

CERCLA Risk and Dose Calculators

Human Health - Radiological

Cancer risk (1×10^{-6})

- PRG (soil, water and air) 2002
- BPRG (inside buildings) 2007
- SPRG (outside surfaces) 2009

Dose (millirem per year)

- DCC (soil, water and air) 2004
- BDCC (inside buildings) 2009
- SDCC (outside surfaces) 2009

Human Health - Chemical

- RSL (soil, water, and air) 2008

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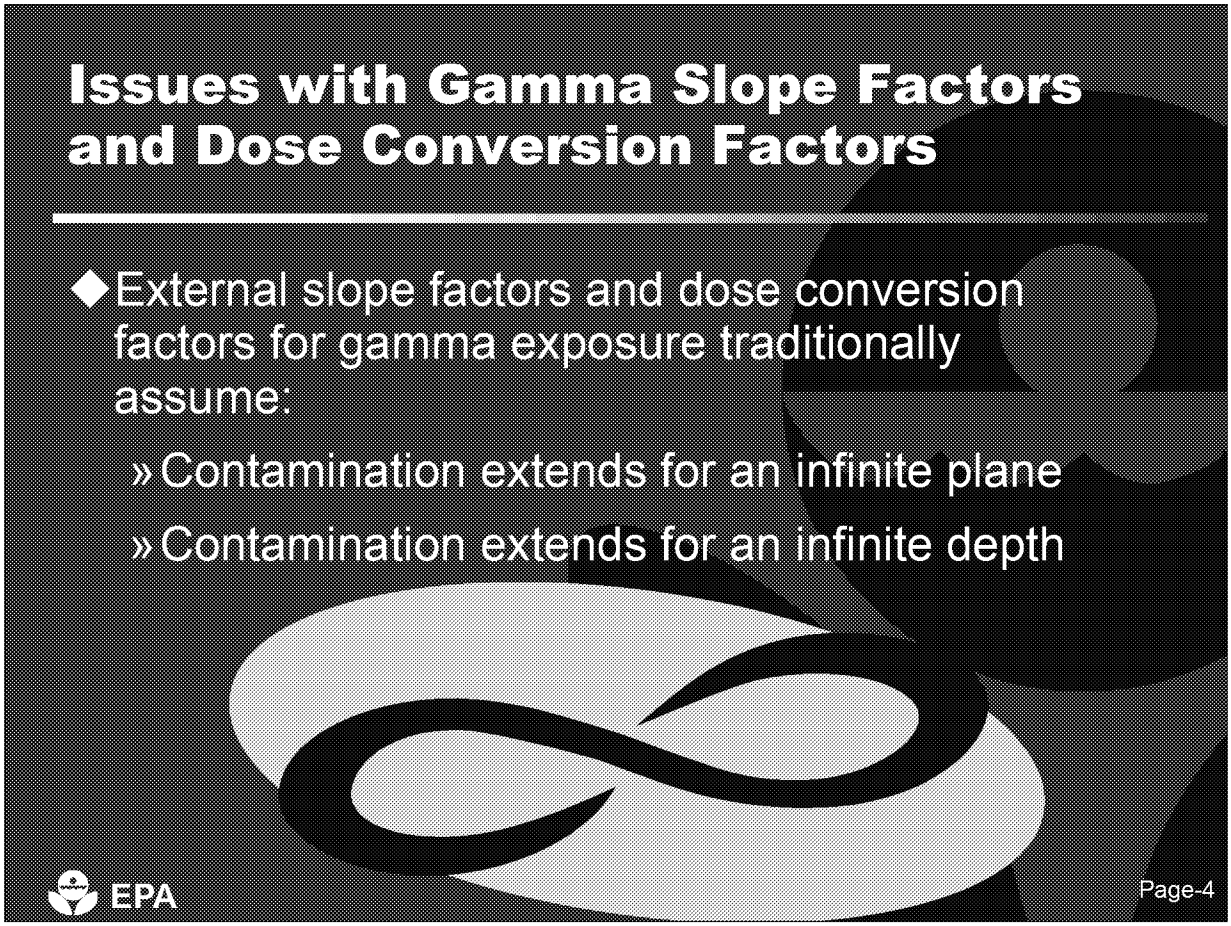

At Superfund radiation sites, EPA generally evaluates potential human health risks based on the radiotoxicity (i.e., the adverse health effects caused by ionizing radiation), rather than on the chemical toxicity, of each radionuclide present. Uranium, in soluble form, is a kidney toxin at mass concentrations slightly above background levels, and is the only radionuclide for which the chemical toxicity has been identified to be comparable to or greater than the radiotoxicity, and for which a reference dose (RfD) has been established to evaluate chemical toxicity. For radioisotopes of uranium, both effects (radiogenic cancer risk and chemical toxicity) should be considered.

Risks from radionuclide exposures should be estimated in a manner analogous to that used for chemical contaminants. That is, the estimates of intakes by inhalation and ingestion and the external exposure over the period of exposure estimated for the land use (e.g., 30 years residential, 25 years commercial/industrial) from the exposure assessment should be coupled with the appropriate slope factors for each radionuclide and exposure pathway. Only excess cancer risk should be considered for most radionuclides (except for uranium). The total incremental lifetime cancer risk attributed to radiation exposure is estimated as the sum of the risks from all radionuclides in all exposure pathways.

Excess cancer risk from both radionuclides and chemical carcinogens should be summed to provide an estimate of the combined risk presented by all carcinogenic contaminants. An exception would be cases in which a person reasonably cannot be exposed to both chemical and radiological carcinogens. Similarly, the chemical toxicity from uranium should be combined with that of other site-related contaminants.

Radiation risk assessments include most of the same exposures that are assessed for exposure to chemicals (such as soil ingestion, fugitive dust inhalation, and drinking water). Risk assessments for radiation also include exposure to external gamma radiation, radon, and consumption of produce (e.g., fruit, vegetables, milk, and beef) grown at the site. Radiation risk assessments do not assess dermal exposure since this exposure pathway is considered insignificant in relation to other exposures that are assessed.

Problem with Infinity

- Assumption of infinite contamination
  - » May lead to overestimation of risk
    - —Contamination does not extend forever over the horizon or down to China
    - —At some point large enough radiation field does mimic infinity

1. PRG and DCC calculator Revisions

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PRG and DCC – new Area Correction Factors

- Source depth-specific area correction factors (ACFs) are now provided.
  - Unique ACFs are now given for the various slope factors (ground plane, 1 cm, 5 cm, 15 cm and infinite depth).
  - Dose rates were determined for 19 areas of contaminated soil which varied from 1 square meter to 100,000 square meters.

PRG and DCC – new Area Correction Factors, continued

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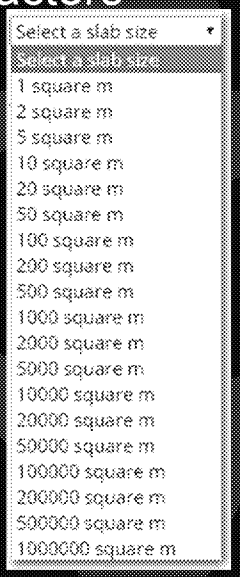
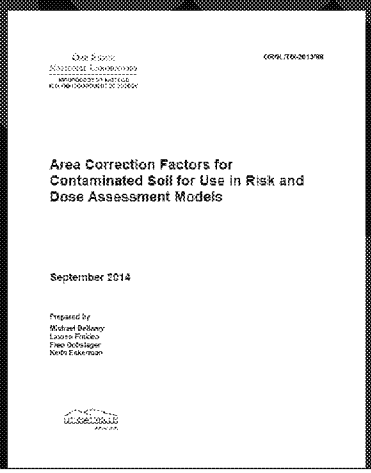
  - » Unique ACFs are now given for the various slope factors (ground plane, 1 cm, 5 cm, 15 cm and infinite depth).
  - » Dose rates were determined for 19 areas of contaminated soil which varied from 1 square meter to 100,000 square meters.



PRG and DCC – new Area Correction Factors, cont.

- Dose rates for the ACF's were computed using Monte Carlo simulation
- This computation was performed using MCNP6
- Analysis and results in 361 page report and appendix.



Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models

September 2014

Prepared by
Michael Bellamy
Laura Pinkas
Fred Schlaeger
Keith Eckerman

EPA

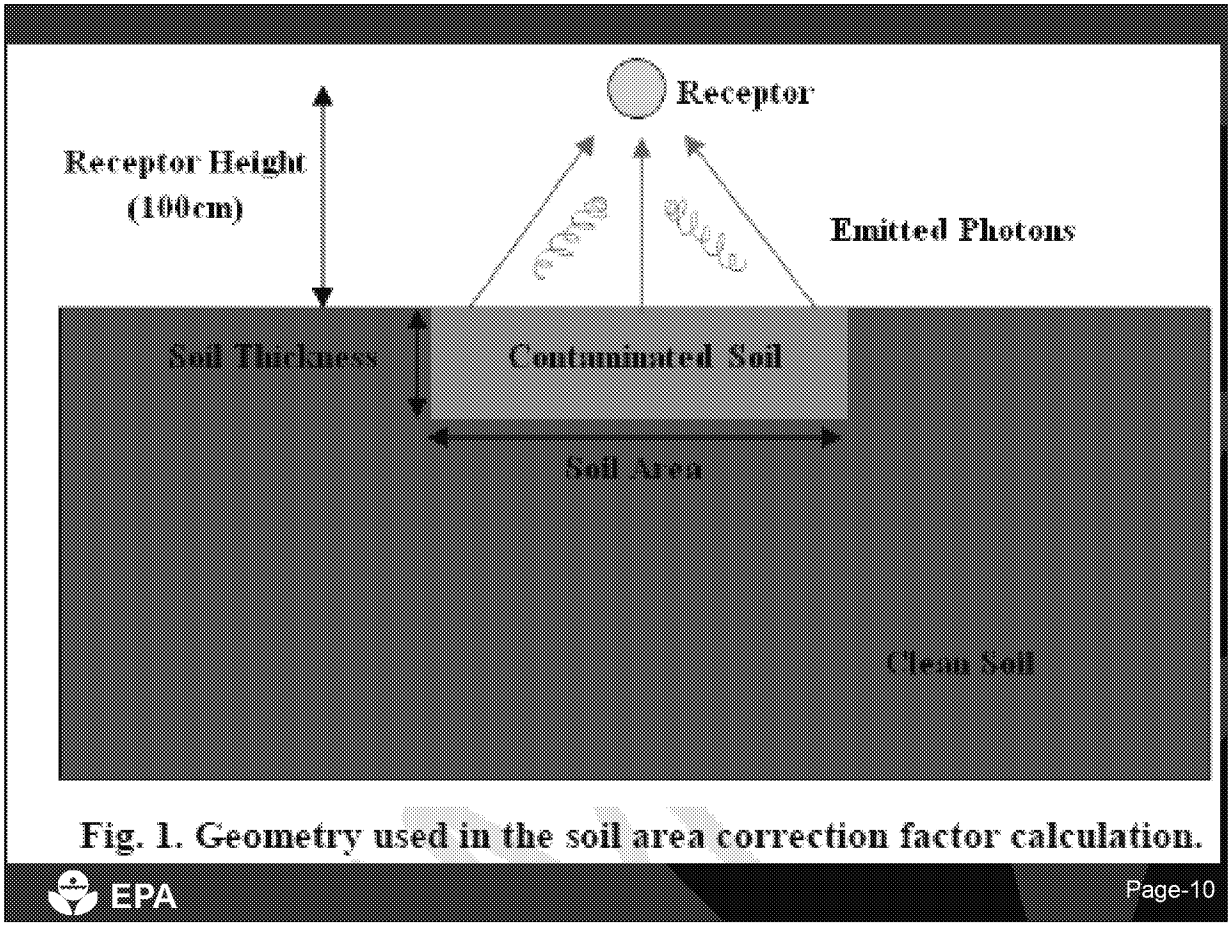
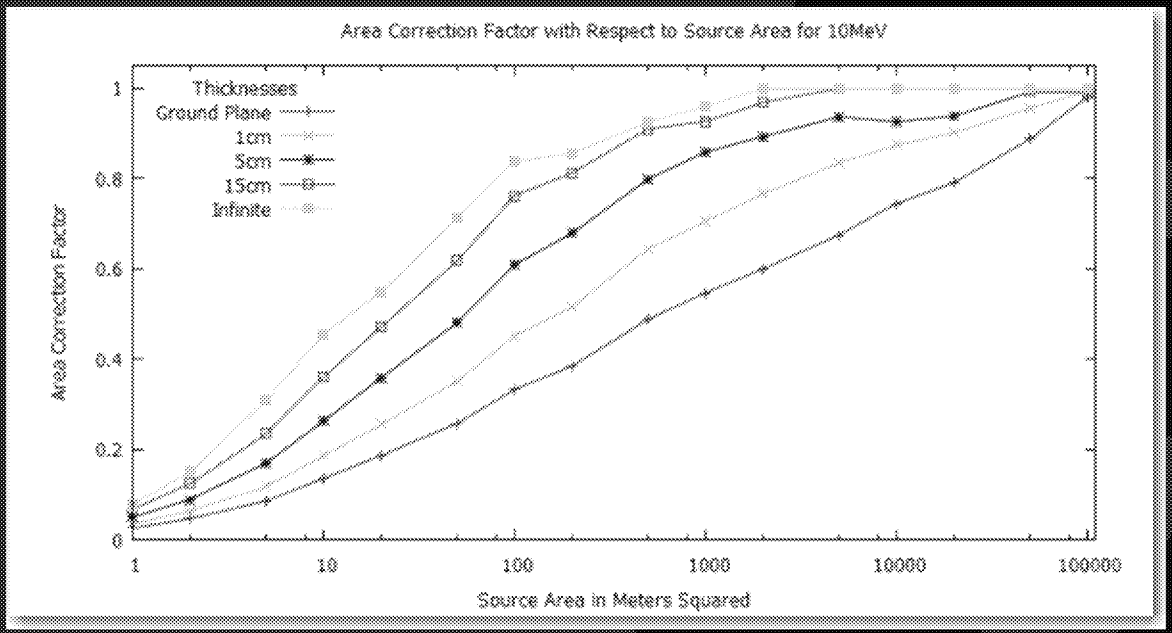


Fig. 1. Geometry used in the soil area correction factor calculation.

Graphs Summarizing Results



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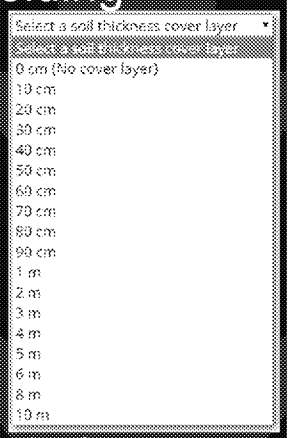
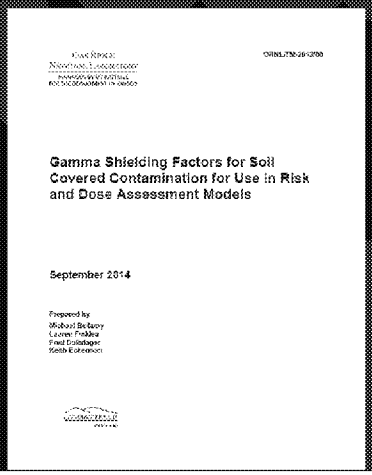
PRG and DCC – add Buried Waste

- Revised PRG and DCC added option for buried waste. Depth-specific gamma shielding factors (GSFs) are now given for:
  - » Various slope and dose conversion factors (ground plane, 1 cm, 5 cm, 15 cm and infinite depth) and various soil cover depths
  - » Does not account for radionuclide transport (e.g., radon through the cap, radionuclide leaching to groundwater)
  - » Assumes cover does not degrade



PRG and DCC – add Buried Waste, cont.

- Dose rates for the GSF's were computed using Monte Carlo simulation
- This computation was performed using MCNP6
- Analysis and results in 190 page report and appendix



Gamma Shielding Factors for Soil Covered Contamination for Use in Risk and Dose Assessment Models

September 2014

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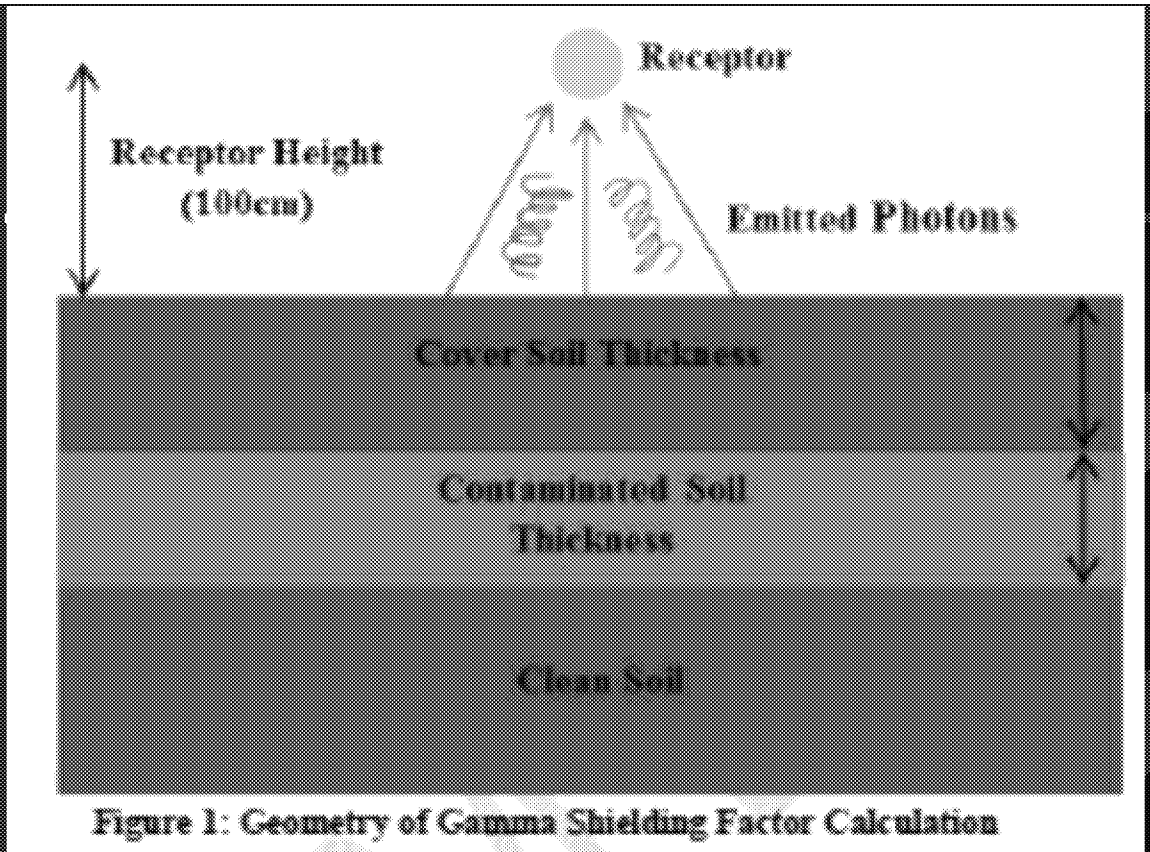

Figure 1: Geometry of Gamma Shielding Factor Calculation

Graphs Summarizing Results

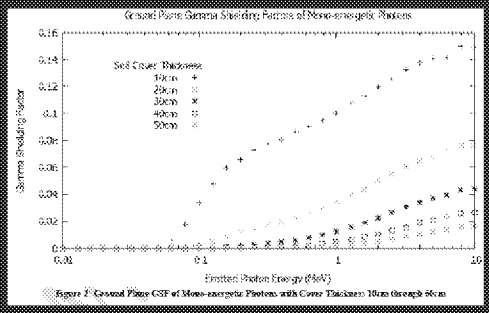

Figure 3: Ground Plane GSF of Mono-energetic Photons with Cover Thickness 10cm through 50cm

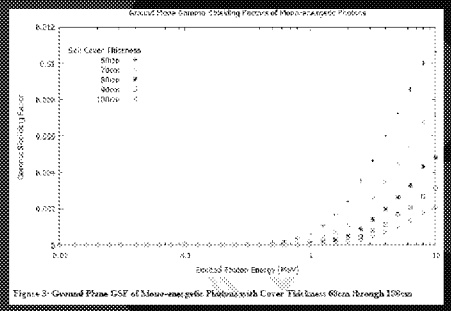

Figure 3: Ground Plane GSF of Mono-energetic Photons with Cover Thickness 60cm through 100cm

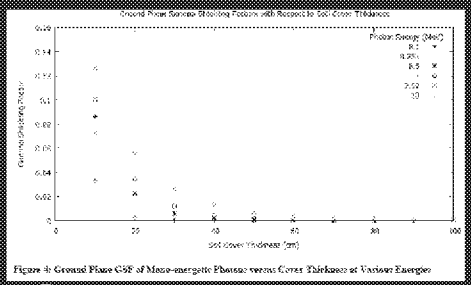

Figure 4: Ground Plane GSF of Mono-energetic Photons versus Cover Thickness at Various Energies

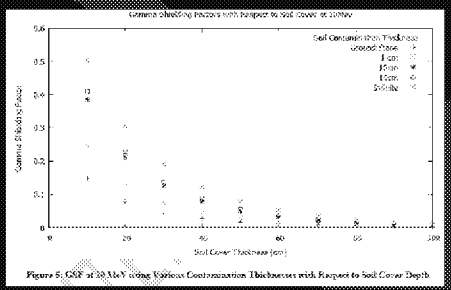

Figure 5: GSF of 10 MeV using Various Contamination Thicknesses with Respect to Soil Cover Depth

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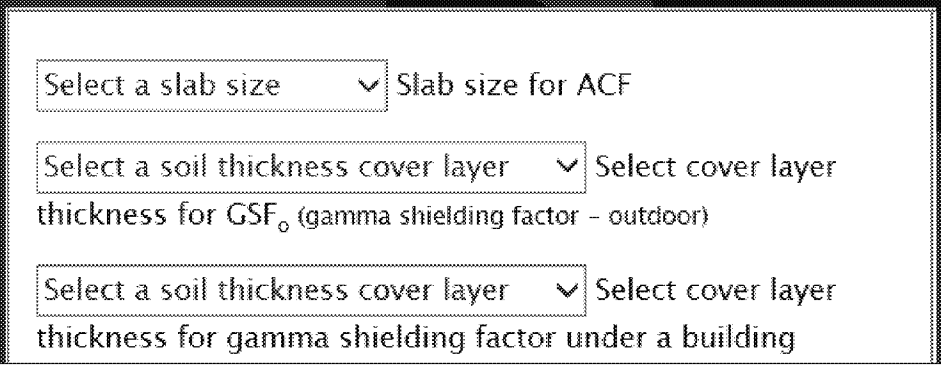
PRG and DCC – NEXT add buried soil under Building

- Currently GSF from buried soil only applies to receptor outside, foundation is considered in contact with waste
- Next PRG/DCC revisions will add separate GSF for buried soil for receptors indoors



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2. BPRG and BDCC calculator Revisions

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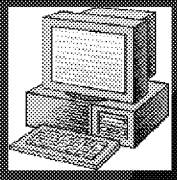
Building PRG (BPRG) Calculator

- Establish 1 x 10^{-6} risk based PRGs for ***inside*** radioactively contaminated buildings
- Equations and parameters are derived from latest EPA chemical methodology (e.g., assessment at World Trade Center)
  - » Adjusted to account for technical differences posed by radiation



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The NCP sets forth nine criteria for selecting Superfund remedial actions. These evaluation criteria are the standards by which all remedial alternatives are assessed and are the basis of the remedy selection process. The criteria can be separated into three levels: threshold, balancing, and modifying. The first two criteria are known as "threshold" criteria. While every Superfund site is unique (whereby cleanups must be tailored to the specific needs of each site), the threshold requirements must be met at every site:

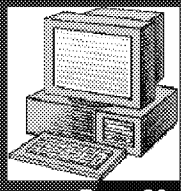
CERCLA requires that all remedial actions at Superfund sites must be protective of human health and the environment. Therefore, cleanup actions are developed with a strong preference for remedies that are highly reliable, provide long-term protection, and provide treatment of the principle threat to permanently and significantly reduce the volume, toxicity, or mobility of the contamination.
CERCLA specifically requires Superfund actions to attain or waive the standards and requirements found in other state and federal environmental laws and regulations. This mandate is known as compliance with "applicable or relevant and appropriate requirements" or ARARs.□□Site cleanups should protect groundwaters that are current or potential sources of drinking water to drinking water standards whenever practicable. The standards include federal Maximum Contaminant Levels (MCL) promulgated under the Safe Drinking Water Act and more stringent state drinking water standards.

BPRG Exposure scenarios

- BPRG calculator includes 2 land use scenarios
  - Residential
  - Indoor worker
- Both land uses include 3 exposure routes
  - Settled dust
  - Ambient air
  - **Direct external exposure**
    - **Surface**
    - **Volumetric**

Building Dose Cleanup Concentrations (BDCC) ARAR Dose Calculator

- BDCC Purpose: to establish BCCs for Inside Buildings for single dose limit ARARs (# mrem/yr)
- BDCC includes 2 land use scenarios (Residential, Indoor Worker)
- 2 land uses include 3 exposure routes (Settled dust, Fixed Direct External 3-D, Ambient Air)
- Equations similar to those used for BPRG calculator, except dose conversion factors used instead of slope factors



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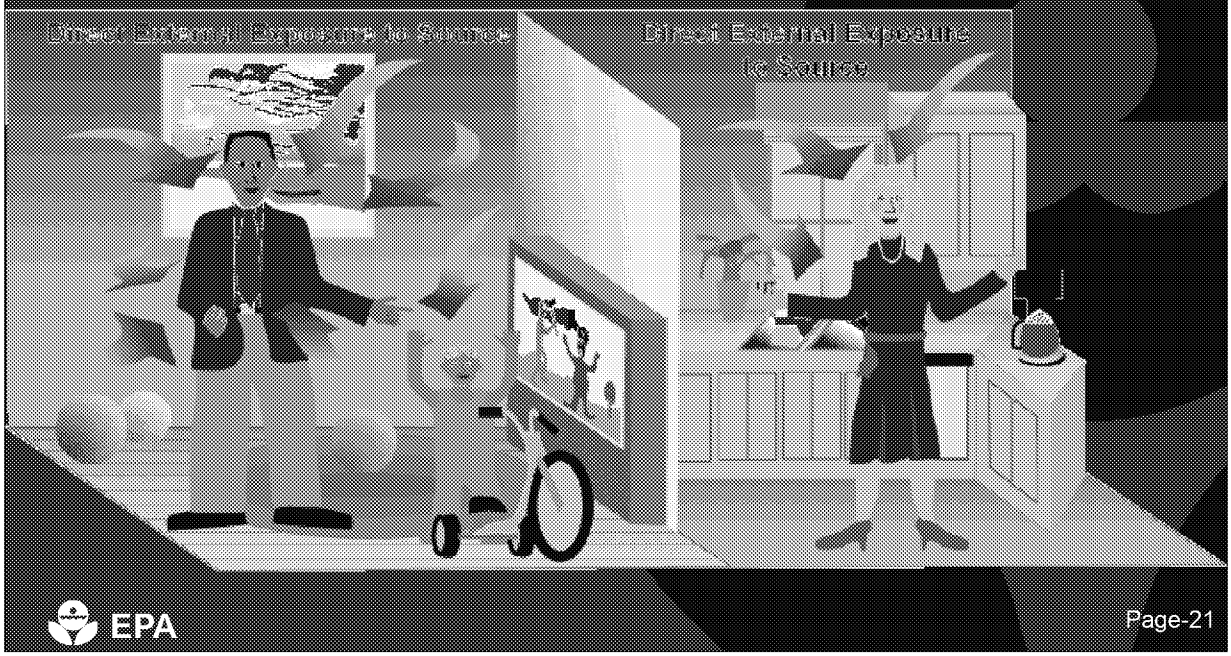
An approach similar to that taken for calculation of PRGs may also be used to calculate soil "compliance concentrations" based upon various methods of dose calculation.

A set of simple equations for target dose rate (e.g., either critical organ dose or single limits), radionuclide dose conversion factor (DCF), and intake/exposure parameters will be presented for use in calculating soil cleanup concentrations. These equations will be identical to those in the PRG for Radionuclides, except that the target dose rate (ARAR based) will be substituted for the target cancer risk (1 x 10-6), the period of exposure is one year to indicate year of peak dose, and a DCF will be used in place of the slope factor.

Please note that the target dose rate is generally a cleanup level when a dose standard is an ARAR (other than single dose limits greater than 15 mrem/yr such as NRC's 25/100 mrem/yr decommissioning rule), while the target risk number of 10-6 is a preliminary number.

Site decision-makers should choose the DCFs (ICRP 2, 30, or 60) required by the ARAR. Note that this calculator does not address ICRP 2. If DCFs are not specified within the regulation (for example, specifically required for compliance within the Code of Federal Regulations for a federal standard that is being complied with as an ARAR), then site decision-makers should generally use ICRP 2 DCFs for whole body and critical organ dose limits (e.g., 25/75/25 and 25/75 mrem/yr dose limits), and generally use ICRP 60 DCFs for single limit standards (e.g., 10 mrem/yr).

Direct External - Residential



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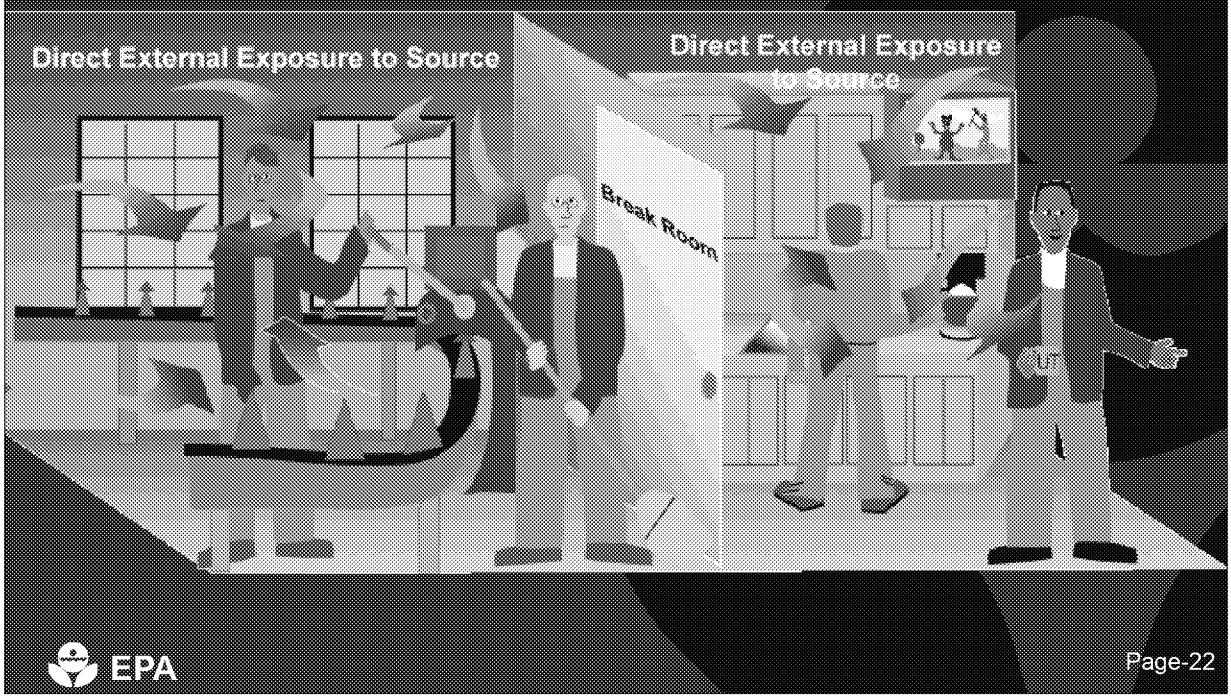
Direct External - Workers



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BPRG/BDCC Surface Factors for Rooms (F_{surf}) – Room size

- 5 Room sizes
  - 10 x 10 x 10 feet
  - 50 x 50 x 10 feet
  - 100 x 100 x 10 feet
  - 200 x 200 x 20 feet
  - 400 x 400 x 40 feet

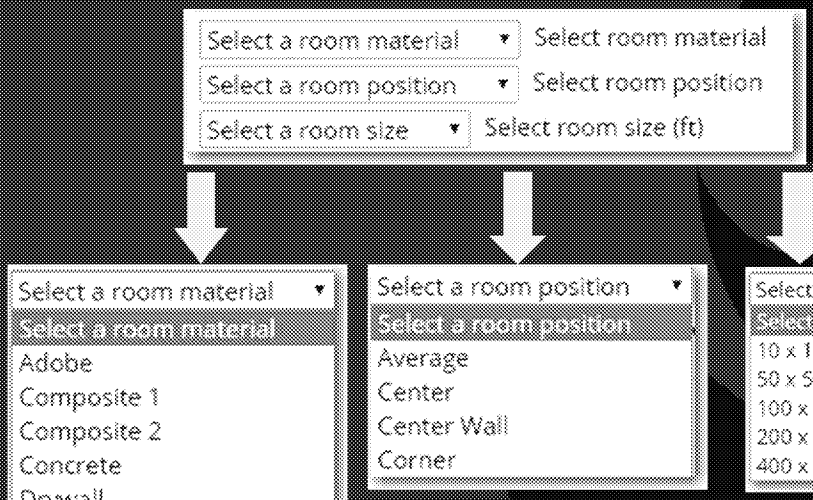
BPRG/BDCC Surface Factors for Rooms (F_{surf}) – Recepter Location

- 4 Receptor Locations in each of the 5 room sizes
  - Averaged across all room positions
  - Center of room
  - Corner of room
  - Center of wall

BPRG/BDCC Surface Factors for Rooms (F_{surf}) – Room Material New

- 7 Room Materials for each receptor locations and room sizes
  - Adobe
  - Composite 1 room material = drywall room, glass window, wooden doors, drywall walls, concrete floor, drywall ceiling
  - Composite 2 room material = concrete room, wooden doors, concrete floor, drywall ceiling
  - Concrete
  - Drywall
  - Glass
  - Wood

BPRG/BDCC Surface Factors for Rooms (F_{surf}) – New



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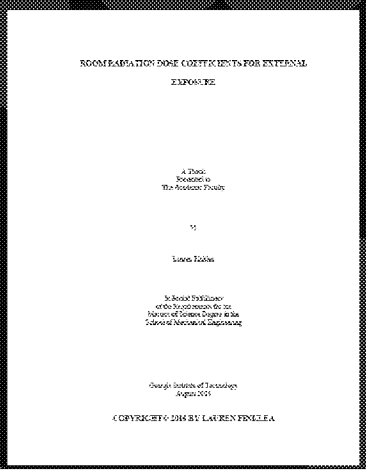
BPRG/BDCC Surface Factors for Rooms (Fsurf)

- Surface factors for rooms were computed using Monte Carlo simulation
- This computation was performed using MCNP6
- Analysis and results in 408 page thesis



ROOM RADIATION DOSE COEFFICIENTS FOR EXTERNAL EXPOSURE

A Thesis
Presented to
The Academic Faculty

by

Lauren Finkle

In Partial Fulfillment
of the Requirements for the
Master of Science in Engineering
in
Nuclear and Radiological Engineering

Georgia Institute of Technology
August 2015

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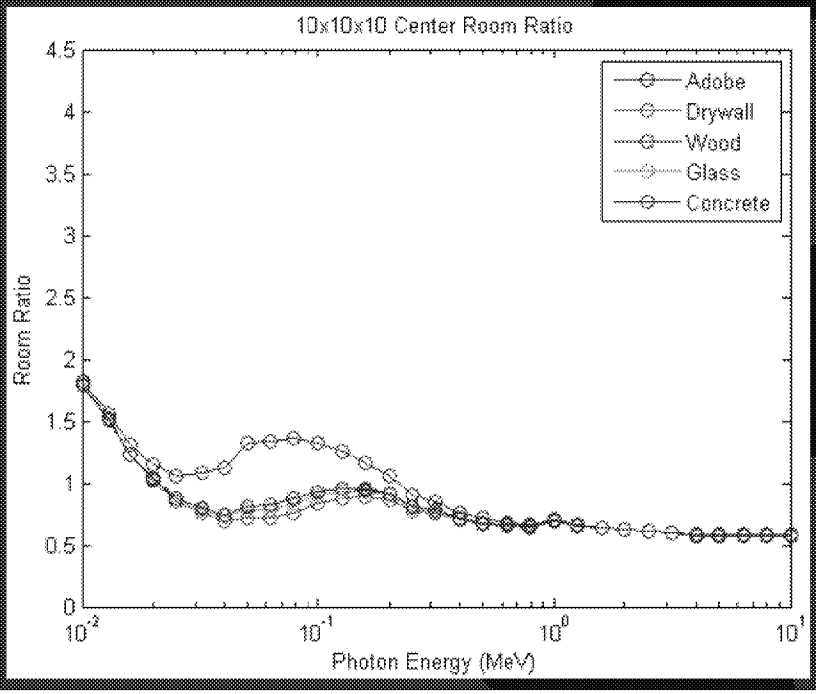
Surface contamination of 10x10x10 room ratio using center of room position



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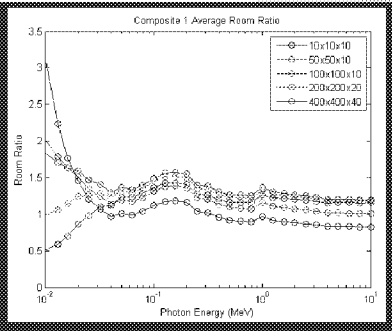
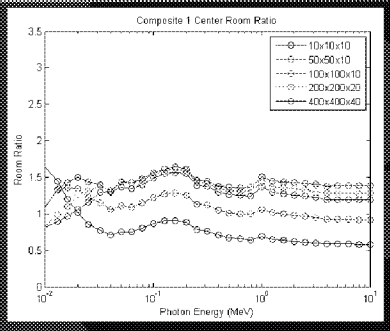
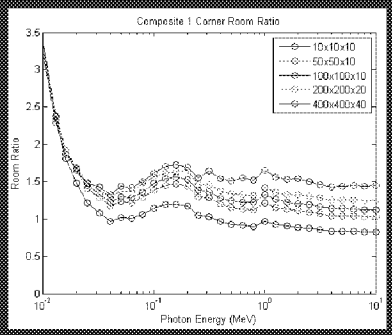
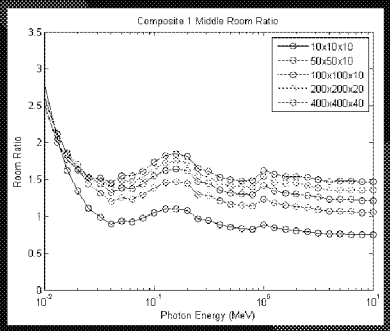
Composite 1 room ratios for all room sizes with surface contamination – average, center, corner,









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BRPG/BDCC Recommendations

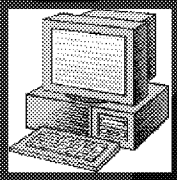
- Defaults toward most conservative combination (for both room size and location) for each radionuclide
- Recommend site-specifically pick room size.
- Usually pick average location unless site-specific information indicates receptor will spend most time in one location

3. SPRG and SDCC calculator Revisions

EPA

Surfaces PRG (SPRG) Calculator

- Establish 1 x 10^{-6} risk based PRGs for radioactively contaminated ***outside*** hard surfaces (e.g., slabs, pavement, sidewalks, sides of buildings)
- Derived from rad PRG and BPRG calculators



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Five of the criteria are known as the "balancing" criteria. These criteria are factors with which tradeoffs between alternatives are assessed so that the best option will be chosen, given site-specific data and conditions.

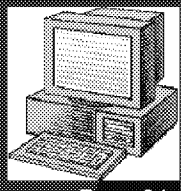
The criteria balance long-term effectiveness and permanence; reduction of toxicity, mobility, or volume; short-term effectiveness; implementability; and cost.

SPRG Exposure Scenarios

- SPRG includes 3 land use scenarios
  - Residential
  - Indoor Worker
  - Outdoor Worker
- 3 land uses include 3 exposure routes
  - Settled dust (street level)
  - **3-D Direct External (street level)**
    - **—Surface and Volumetric**
  - **2-D Direct External (slabs)**
    - **—Surface and Volumetric**

Surface Dose Cleanup Concentrations (SDCC) ARAR Dose Calculator

- SDCC Purpose: to establish DCCs for Outside Hard Surfaces for single dose limit ARARs (# mrem/yr)
- SDCC includes 3 land use scenarios (Residential, Indoor Worker, Outdoor Worker)
- 3 land uses include 3 exposure routes (Settled dust, Fixed Direct External 3-D, Fixed Direct External 2-D (slabs))
- Equations similar to those used for SPRG calculator, except dose conversion factors used instead of slope factors



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An approach similar to that taken for calculation of PRGs may also be used to calculate soil "compliance concentrations" based upon various methods of dose calculation.

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Site decision-makers should choose the DCFs (ICRP 2, 30, or 60) required by the ARAR. Note that this calculator does not address ICRP 2. If DCFs are not specified within the regulation (for example, specifically required for compliance within the Code of Federal Regulations for a federal standard that is being complied with as an ARAR), then site decision-makers should generally use ICRP 2 DCFs for whole body and critical organ dose limits (e.g., 25/75/25 and 25/75 mrem/yr dose limits), and generally use ICRP 60 DCFs for single limit standards (e.g., 10 mrem/yr).

SPRG/SDCC Positioning Factors: Building Heights

- 5 Building heights
  - 12 feet 6 inches
  - 30 feet
  - 59 feet
  - 150 feet
  - 200 feet

SPRG/SDCC Positioning Factors: Receptor Location

- 3 Receptor Locations for each of the 5 building heights
  - Adjacent to Building
  - Middle of Sidewalk
  - Middle of Street

3-D External Residential Building Materials

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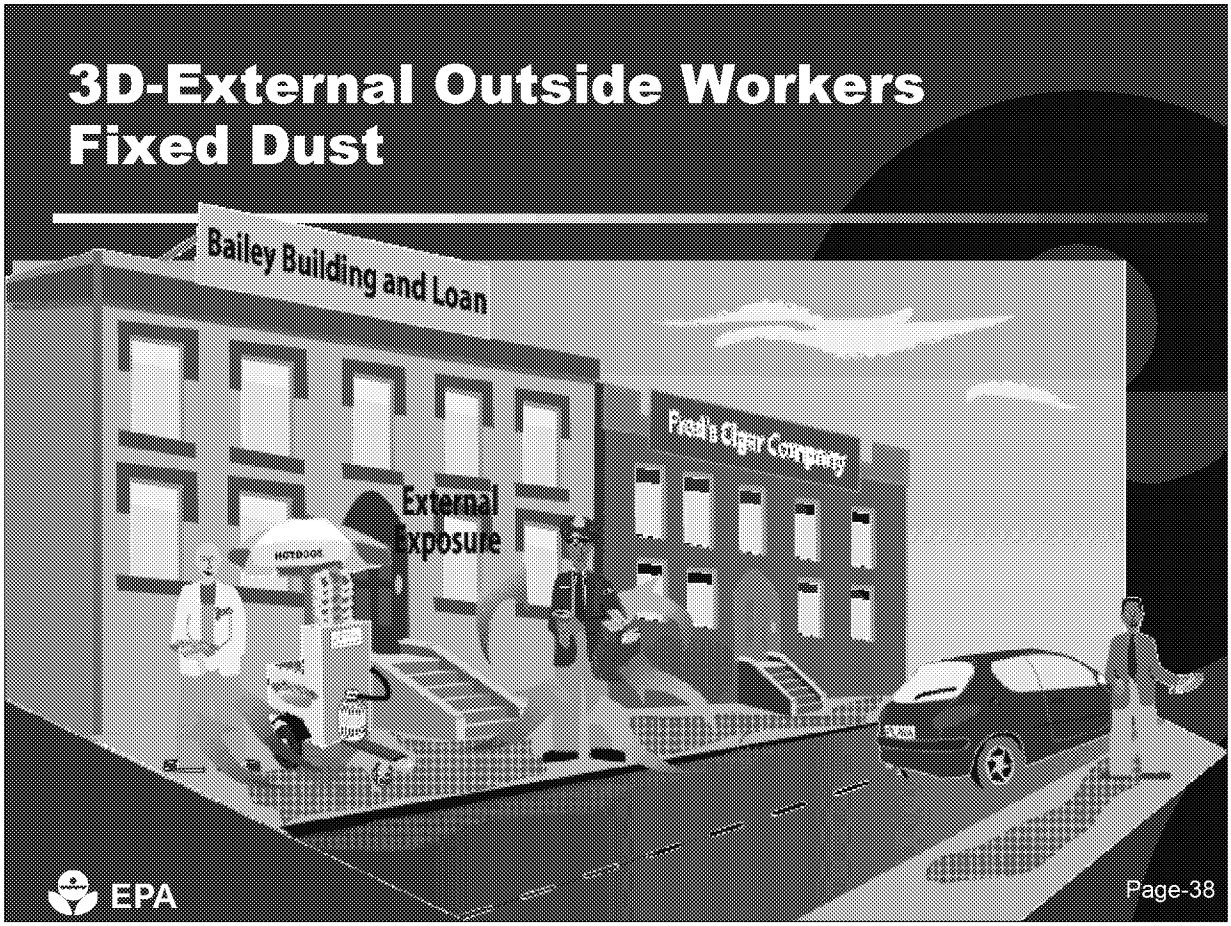
3D-External Outside Workers Fixed Dust



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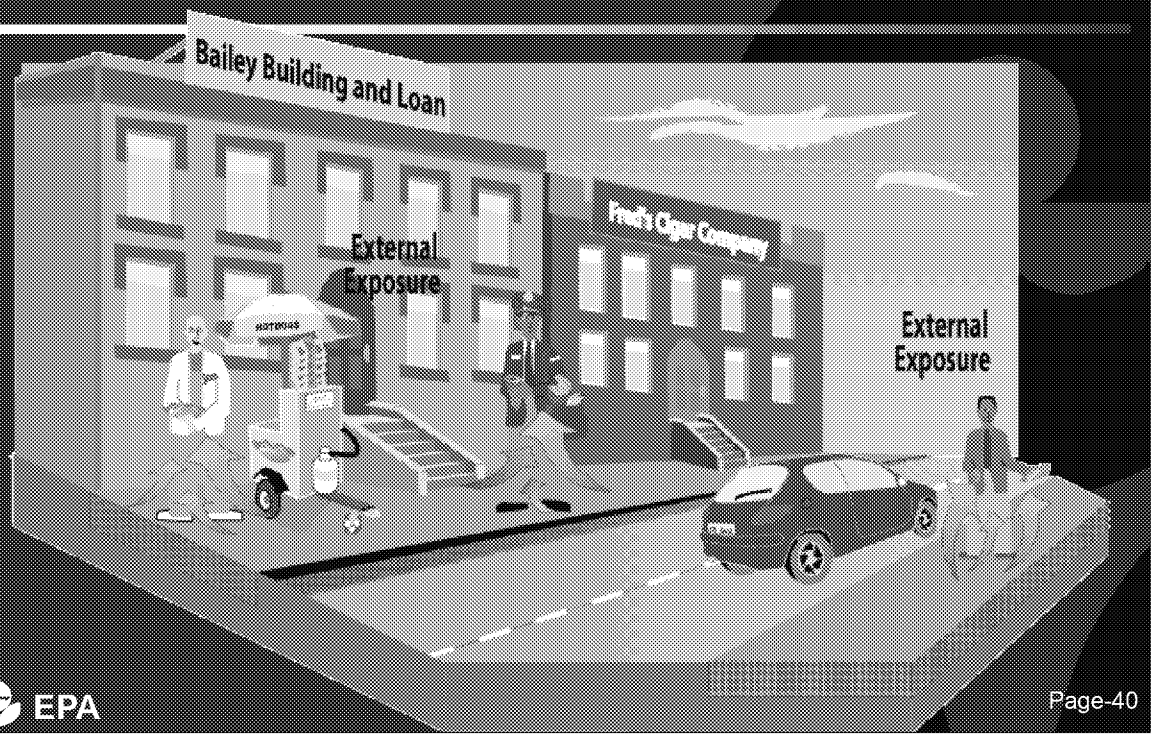
SPRG/SDCC Building Slabs

- Includes new ACF
- Same site sizes, but different ACF for each size for over 800 radionuclides
- Added to PRG and DCC calculators

SPRG/SDCC 2-D External Outside Workers Contaminated Building Slabs



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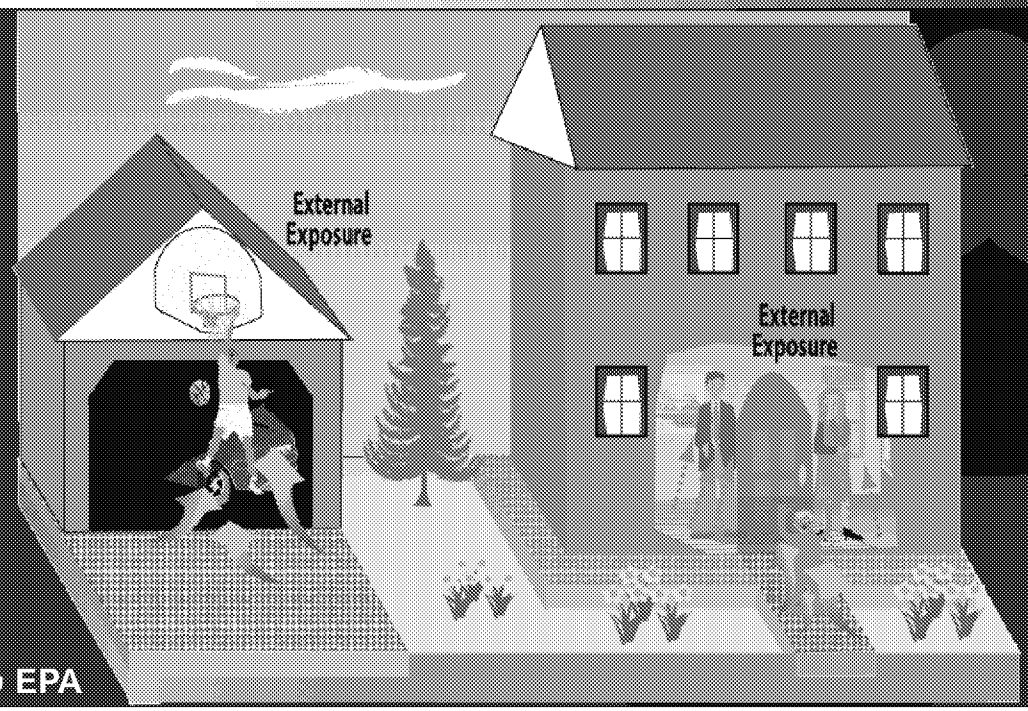
SPRG/SDCC 2D External Residential Fixed Dust



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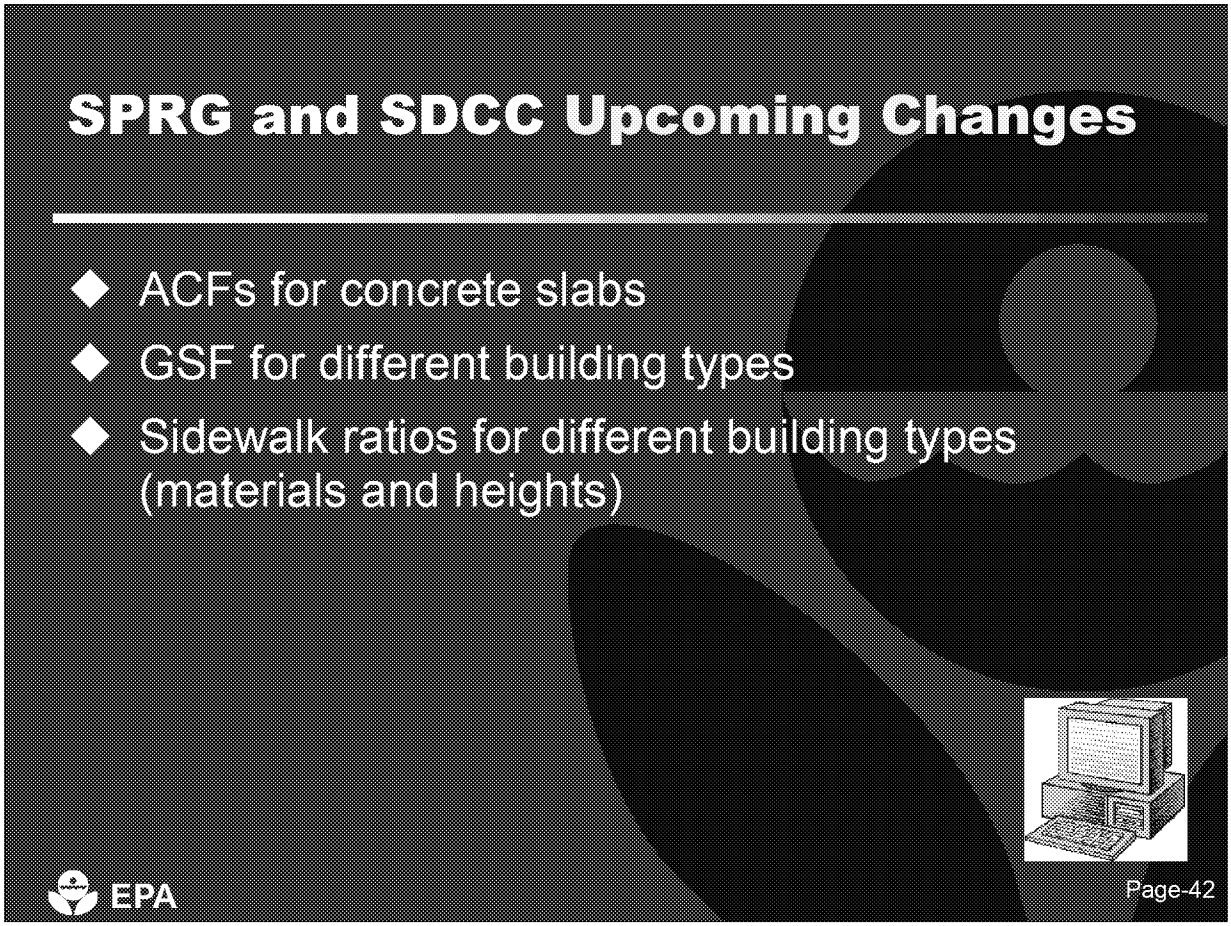

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For More Information

For further information or questions:

- Stuart Walker
  - Phone: (703) 603-8748
  - Fax: (703) 603-9133
  - Email: Walker.Stuart@epa.gov

Risk and Dose Calculators are Freely Available on the Internet

- PRG calculator
  http://epa-prgs.ornl.gov/radionuclides/
- DCC calculator
  http://epa-dccs.ornl.gov/
- BPRG calculator
  https://epa-bprg.ornl.gov/
- BDCC calculator
  https://epa-bdcc.ornl.gov/
- SPRG calculator
  https://epa-sprg.ornl.gov/
- SDCC calculator
  https://epa-sdcc.ornl.gov/

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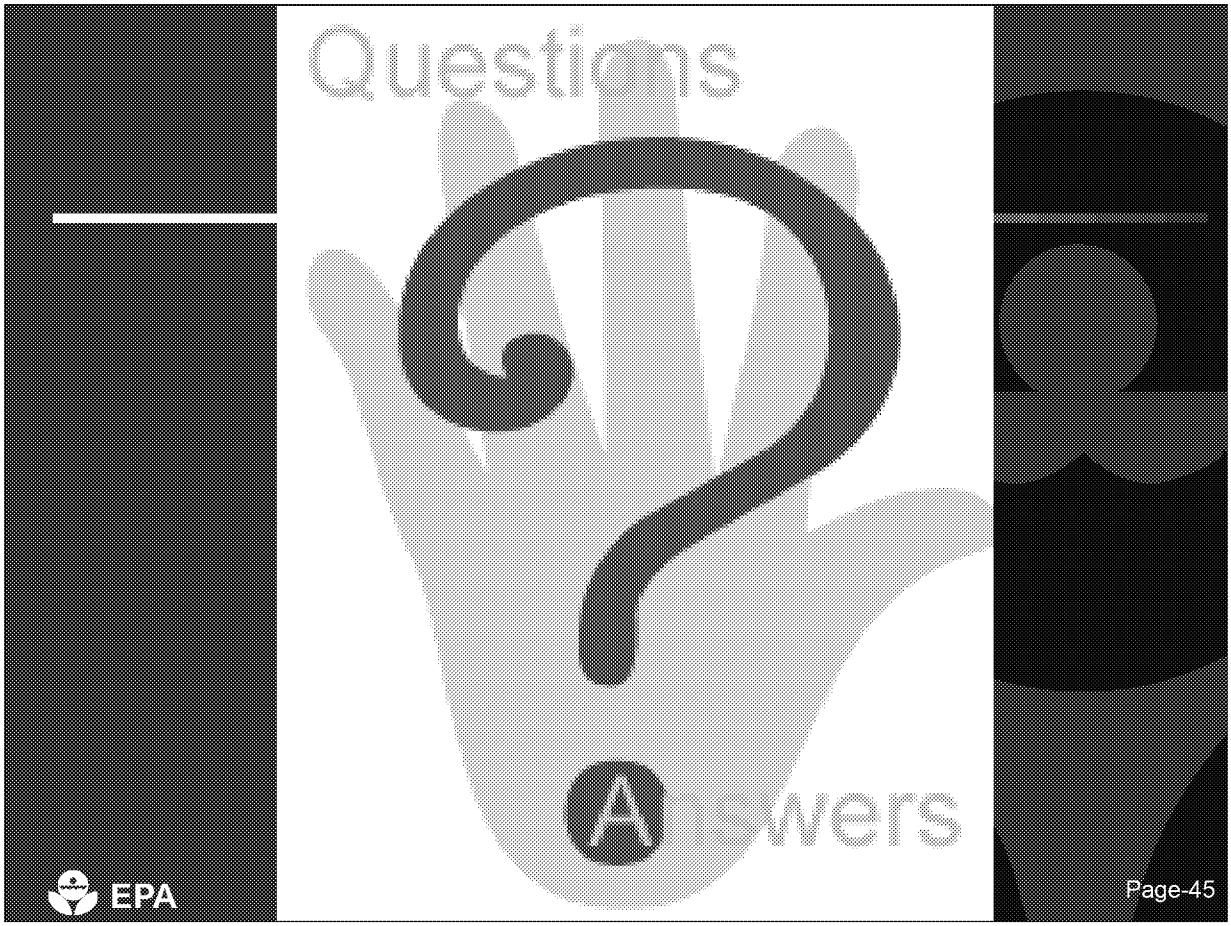
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